OPTICAL SYSTEM WITH REDUCED BACK REFLECTION

This application is a continuation-in-part of US Serial No. 10/610,256, filed June 30, 2003, entitled "A High Speed Optical System", the entire contents of which are herein incorporated by reference.

Background

The present invention relates to optical systems for delivering light from a light source to a destination such as a detector, and more particularly, to such systems that are adapted to reduce back reflection from the destination back to the light source.

Optical technology is used in a wide variety of fields including telecommunications, computers, and medical fields. In many applications, a light guide - such as an optical fiber - is used to deliver a light signal from a light source to a light detector. An important consideration in many of these systems is the optical coupling performance between the light source, the optical fiber, and the light detector. In many cases, the optical fiber is simply "butt-coupled" to the light source and/or light detector. While this may be adequate for some applications, it has been found that in some cases, some of the light that is delivered to the light detector is reflected by the light detector back into the optical fiber, and in some cases, back into the light source. Such back reflection can in some cases create significant noise. For example, it has been found that such back reflections can create optical feedback in some light sources, which can produce increased jitter and increased Reflective Intensity Noise (RIN). Back reflections can also cause interferometric noise in some light sources by converting some light source phase noise into light source intensity noise. For optical communications systems, this can result in increased bit error

rates (BER), and reduced performance. For other applications, such as computer and medical applications, this noise can result in reduced system performance and/or reduced reliability.

Summary

The present invention is directed to a method and apparatus for reducing back reflection into an optical system. In one illustrative embodiment, an optical element is provided between a light source and a light detector. The optical element is adapted to direct light delivered by the light source to the light detector. In some cases, the optical element is further adapted to reduce or prevent light that is reflected off the detector from substantially coupling back to the light source. This may be accomplished by, for example, including an axicon type function in the optical element. It is contemplated that the light source may be an optoelectronic device, an optical fiber driven by an optoelectronic device, or any other light source, as desired.

In one illustrative embodiment, the optical element may include a plano-convex lens that has a flat side and a convex side. In this embodiment, the light source may be positioned adjacent to the flat side, and the detector may be positioned adjacent to but spaced from the convex side. The plano-convex lens may be configured to receive a light beam from the light source and produce an annular shaped light pattern on the detector surface. When the annular shaped light pattern strikes the detector, most of the light reflected by the detector surface will not be directed or focused back to the light source by the plano-convex lens. This may help reduce the optical feedback at the light source, which can reduce jitter and Reflective Intensity Noise (RIN) in the system. This may also reduce the interferometric noise at the light source. With the reduced noise, decreased bit error rates (BER), and increased performance may be achieved.

While an annular light pattern is described above in one illustrative embodiment, it is contemplated that any light pattern may be used that helps reduce the amount of back reflection that is coupled back into the light source. In many cases, this may correspond to a light pattern that has a reduced light intensity near the center of the light pattern, such as an annular, semi-annular or other like pattern.

Alternatively, or in addition, it is also contemplated that the optical element may have a focal length, and that the detector may be placed in front of or behind the focal point. This may help defocus the light at the detector, which may help reduce the amount of back reflection that is coupled back into the light source. The detector may also have an anti-reflective coating to further help reduce the amount of back reflection, if desired.

Brief Description of the Drawings

Figure 1 is a schematic view of an optical system according to an illustrative embodiment of the present invention;

Figure 2 is a spot diagram of an illustrative light pattern on the detector of Figure 1;

Figure 3 is a spot diagram of an illustrative return spot on the light source of Figure 1;

Figures 4 and 5 show cross-sectional views of lenses having slope discontinuities; and

Figure 6 reveals several focal adjustments of an optical element.

Description

Figure 1 is a schematic view of an optical system 100 according to an illustrative embodiment of the present invention. In the illustrative embodiment shown in Figure 1, a light source 110 emits light rays 120, which pass through optical element 130. Suitable light sources include, for example, an optical fiber that delivers light, a laser such as a Vertical Cavity Surface

Emitting Laser (VCSEL), a Light Emitting Diode (LED), or any other suitable device or element, or combination of suitable devices or elements, capable of producing or delivering light. After passing through optical element 130, light rays 140 impinge on the surface 150 of a detector 160. The detector 160 may be any suitable light detector, as desired.

In the illustrative embodiment, the light rays 120 are conditioned by the optical element 130 into light rays or signals 140, which form an annular light pattern on the detector surface 150, as better shown in Figure 2. Figure 2 shows a spot diagram of an illustrative light pattern produced by optical element 130 on the detector surface 150.

When the illustrative annular shaped light pattern (see Figure 2) strikes the detector surface 150 of detector 160, most of the reflected light is not directed by the optical element 130 back to the light source 110, as shown by Figure 3. Figure 3 shows the back reflection or return spot on the light source 110. As can be seen, the back reflection is small (< 10%), indicating that the optical feedback at the light source 110 is reduced, which can reduce jitter, Reflective Intensity Noise (RIN), and/or interferometric noise at the light source 110. As indicated above, this reduced back reflection noise may help provide a decreased bit error rate (BER) and/or an increase in performance of the optical system. More specifically, and in a fiber communications example, the reduced back reflection may help meet the return loss specification of Ethernet and fiber channels and improve the performance of the fiber communications system.

In the illustrative embodiment shown in Figure 1, the optical element 130 is a plano-convex lens. The plano (i.e. flat) side 210 of the lens 130 may act as a fiber stop to a light source (e.g. fiber) 110. In some embodiments, the plano side 210 of the lens 130 may make physical contact with the fiber 110 facet. This physical contact may be maintained using spring loading.

To help reduce back reflection caused by the boundary between the plano side 210 of the lens 130 and the fiber 110 facet, the index of refraction of the lens material may be selected to match or substantially match the index of the fiber 110 core. In one illustrative embodiment, the optical element 130 is one piece and made or molded from Ultem^{R} 1010, which is a General Electric Company plastic. In some cases, an optical grease or optical adhesive may be placed between the plano side 210 of the lens 130 and the fiber 110 facet, if desired.

As shown in Figure 2, the convex side 220 of the lens 130 may be configured to form an annular or ring spot pattern on the detector surface 150. When an annular shaped light pattern impinges on the detector surface 150, most of the reflected light will not be directed or focused by the plano-convex lens 130 back to the light source 110. This may help reduce the optical feedback to the light source, which can reduce jitter, Reflective Intensity Noise (RIN), and interferometric noise in the system. As such, decreased bit error rates (BER), and increased performance may be achieved.

While an annular light pattern is shown above in Figure 2, it is contemplated that any light pattern that helps reduce the amount of back reflection that is coupled back into the light source 110 may be used. In many cases, this may correspond to a light pattern that has a reduced light intensity near the center of the light pattern on the detector surface 150. That is, in many cases, the optical element 130 may redistributed the power of the light source 110 from the center to the outskirts of the beam that is projected on to detector surface 150.

Alternatively, or in addition, it is contemplated that the optical element 130 may have a focal length that images the light from the light source 110 onto a focal point 162 or focal plane, as desired, and the detector 160 may be placed in front of or behind the focal point 162 or focal

plane. This may help defocus the light at the detector surface 150, which may help reduce the amount of back reflection that is coupled back into the light source 110. The detector surface 150 may also have an anti-reflective (AR) coating to further help reduce the amount of back reflection, if desired. While the optical element 130 is shown as a plano-convex lens in Figure 1, it is contemplated that the optical element 130 may be any optical element that produces a light pattern on the detector surface 150 that helps reduce the back reflection into the light source 110.

Attaining an annular distribution of light on the detector surface 150 may be achieved in any number of ways. For example, and in one illustrative embodiment, an axicon lens, also known as conical lens or rotationally symmetric prism, may be used to convert a parallel laser beam into a ring, a doughnut shaped ablation or an annular intensity profile.

In some cases, an appropriate slope discontinuity may be provided in the surface 220 of the optical element 130 at or near the optical axis 130, although this is not required in all embodiments. The slope discontinuity may help provide the axicon function to optical element 130. An illustrative surface 220 of an axicon optical element having a slope discontinuity at optical axis 230 is shown in Figure 4. Line 240 shows the slope of the upper part of surface 220 at optical axis 230 ($r = 0$). Line 250 shows the slope of the lower part of surface 220 at optical axis 230. As one follows surface 220 across axis 230, there is a disruptive change of slope from slope 240 to slope 250. Slope discontinuities may be implemented in various ways. Figure 5 shows a slope or curvature discontinuity 340 as a small notch-like shape, cusp, indentation or protrusion in surface 220 at area 260 about optical axis 230. Discontinuity 340 may be sharp, abrupt, rough or smooth. Discontinuity 340 may be of any shape or contour that helps enhance the axicon function. Elsewhere, the slope may be continuous, such as a function of the distance

from optical axis 230 or of the radius, except at optical axis 230. In some cases, slope discontinuity 340 of surface 230 may appear imperceptible to the eye. Apart from point or area 260, surface 220 may be aspherical or spherical, depending on the application.

Alternatively, or in addition, much or all of the surface 220 of optical element 130 may be configured such that an annular or ring pattern of light 140 is transmitted onto the detector surface 150 of detector 160. For example, the surface 220 may cone shaped, with the tip of the cone at the vertex of the surface. Surface 220 may also be rotationally symmetric about the optical axis (e.g. z axis), and described by a single parameter θ, where θ is the angle measured between the plane normal to the z axis at the vertex of the cone and the surface 220. The surface sag of the surface 220 may be defined by, for example:

$$z = \tan(\theta) r$$

where "z" is the surface sag and "r" is the radial coordinate in lens units.

Alternatively, the lens surface 220 may be defined by the following formulas, constants and variables:

$$z=\{cr^2/[1+(1-(1+k)c^2r^2)^{1/2}]\}+A_1r^1+A_2r^2$$
$$c=1/R;\ R=-0.3715\ mm$$
$$k=-1.171438E+008$$
$$A_1=0.01270$$
$$A_2=-0.7737mm^{-1}$$

In some illustrative embodiments, an annular light pattern may be produced on detector surface 150 by defocusing the light spot produced by the optical element 130 relative to the detector surface 150. In one illustrative embodiment, detector 160 may be positioned either in front of or behind the focus point or focal plane of optical element 130. This may cause an

annular light intensity pattern on detector surface 150. The area of lower or no intensity in the center of the annular or ring distribution may be referred to as the dark spot of Arago in a well-corrected optic.

Figure 6 reveals three focus positions of an illustrative optical element 130. Detector position 270 shows an annular intensity profile of light 140 launched on detector surface 150. The intensity is shown by coordinate I and the distance from optical axis 23 is shown by coordinate R. Detector position 280 shows a profile having the intensity of light 140 concentrated on or near optical axis 230. Detector position 290 shows an annular intensity profile similar to the profile of detector position 270. Either detector position 270 or 290 may be used to achieve an annular or ring distribution of light intensity on the detector surface 150. It is contemplated that optical system 100 may incorporate either or both of the axicon and defocusing components to attaining an annular light pattern on the detector surface 150.

Although the invention has been described with respect to at least one illustrative embodiment, many variations and modifications will become apparent to those skilled in the art upon reading the present specification. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.